Fermi National Accelerator Laboratory

TM-1453
0818.000

The MADC (Multiplexed ADC) - How to Make Connections to It?

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May 1987

Operated by Universities Research Association Inc. under contract with the United States Department of Energy

1. Introduction

A MADC (Multiplexed ADC) was designed back in 1979 in order to replace old DSE units. However, most of the 120 units that were built went for new installations (i.e., Tevatron and P Bar) rather than for replacing old ones. So, we still have a job to satisfy the original objective.

I haven't heard many complaints about my MADCs, and I could optimistically assume that they are working well. I have received some questions, one of which I had had difficulties in explaining about. That was on the source impedance and how it would affect the accuracy of reading with channels being switched one to another in high speeds. Recently, I analyzed the issue with the SPICE program, and I have some results of the analysis. I am now in a better position to explain it.

In this paper, the author will review some questions on the MADC, and he will try to present answers for readers' convenience.

2.1 Input Cables and Connections

Which cable type should be selected for a given application coaxial or twinaxial? It is determined by (1) how far the source is away from the MADC and (2) how accurately the source voltage is to be read. Generally, a twinaxial cable (e.g., RG108A/U) is recommended. Because it maintains differential connections from the source to the MADC, and because some common mode noises are rejected at the MADC. If the physical separation between the source and the MADC is relatively short, the coaxial cable may be selected. For example, C160 Dipole Function Genarator modules are located one or two racks away. Voltages from these modules are accurately read down to the LSB (i.e., 5 mV) by MADCs.

Fig. 1 shows how input connections are made from the source to the MADC using a twinaxial cable. One notices a few important points in this figure - (1) The high and low connections (+ and - in the figure) of the source are brought right up to the corresponding connections of the MADC, and the low side connection is grounded only at the source, (2) the shield connection is grounded at the source and at the analog entry box, and it is not grounded at the MADC, and (3) the ground points of the analog entry box and the MADC are electrically, physically close each other (i.e., the two objects are usually located in the same rack). One of the frequently asked questions is something like 'Which contact is for the high side of signal in the twinaxial cable? Pin or socket?' The answer[1] is 'The convention for twinaxial cable connection is pin for high and socket for low'.

Users make up cables and connect their sources to the analog entry box. Proper termination of connectors onto the twinaxial cable is crucial to system reliability. Some novice users call us saying something like 'I have checked my source okay. Something must be wrong with the MADC. Can you check it?' In response to a call like this, we usually find nothing wrong with the MADC but something wrong with the cable. Those novice users should learn to check their source at the far end of the cable. They should also learn to tighten up the nut against the connector body with wrenches rather than fingers.

2.2 Source and Its Reference

Sometime ago, a junior engineer asked me something like 'I can check a battery voltage with a DSE. Why can't I do the same thing with yours?' DSE units might have been designed 18 to 19 years ago, and circuits were made out of descrete components. Their multiplexers are known for high leakage. Whereas the newer MADCs were designed 8 years ago, and circuits are made of ICs. The multiplexers used have very low leakage and do not provide enough leakage paths for the inputs of the instrumentation amplifier. Therefore, when the input connections are opened or when someone tries to measure a voltage of a floating battery, a correct value is not read (usually + or - full scale value is shown).

Fig. 2 shows a source connected to the instrumentation amplifier through the multiplexer (See dotted lines through the multiplexer). The inputs of the amplifier see a leakage path through a common mode impedance Rcm with Rs (source impedance) being << Rcm. When the source is floated or when Rcm becomes extremely high, the inputs of the amplifier lose their leakage path and thus the output voltage is affected by input bias currents. Some people suggested to add resistors at the inputs of the amplifier as shown as R_A's in Fig. 2. However, I did not or will not intend to add resistors like these to my circuit with some reasons. The reasons are (1) by adding extra components like these, I shall introduce additional causes for inaccuracy, and (2) it is meaningless to check a floating battery with the MADC. People should stop doing anything like this. I haven't heard anything about floating sources for the past eight years. If someone needs to float his source, I would like to hear from him.

2.3 Source Impedance

One day an operator called me saying something like 'If I plot Channel 15 only, it is okay. But if I plot Channels 14 and 15 together, the channel in question is affected by the other. Something may be wrong with your mux card............' I said to him something like 'New MADCs are quite different from DSEs. Mux cards won't give up so easily. Do yo know what the source impedance is?' Then he told me to talk to Mr. W. I talked to Mr. W and found that he had 4K ohms on his source. The problem was solved by having Mr. W replace 4K ohms with 100 ohms.

'How low should the source impedance be?' Well, this is not an easy question to answer. However, I have done some work to analyze the input circuit and have some results, which may be helpful for the reader to determine the value of his source impedance.

The first thing that one should realize is that the MADC is dynamic, i.e., it switches from one channel to another in high speeds. Fig. 3a shows a basic MADC timing diagram. The cycle time is 9.5 us which comprises of 6 us of settling and 3.5 us of conversion. During the settling time, the input capacitance of the MADC has to be discharged from the previous voltage and to be charged to the current voltage within 6 us. Fig. 3b shows a MADC input circuit diagram, which includes the source Es, its impedance Rs, the cable capacitance C, the capacitance through entry box and its cable estimated to be 420 pF, the resistance through protection circuit and multiplexers 2K ohms, and the stray capacitance in the MADC 100 pF. The leakage through multiplexers and the input resistance of the amplifier are neglected from this high speed circuit analysis.

Fig. 4a shows a simplified circuit which is derived from Fig. 3b. This circuit was analyzed with the SPICE program[2]. In the analysis, one assumes that C1 is initially charged to the current voltage (i.e., V) and C2 is charged to the previous voltage (0 or -10V for this analysis), and that what happens after the switch S is closed is analyzed. Fig. 4b shows a listing of SPICE file when V=8V, R1=1K, C2=6800pF, R2=2K, C2=100pF and IC (initial condition) on C2=0V. Fig. 4c shows a time vs. voltage plot of the above circuit. By examining the plot, one can roughly say something like 'C2 quickly charges up to a voltage governed by

$$\frac{C1}{C1+C2} V + \frac{C2}{C1+C2} V2$$

in speeds related to the time constant R2*C2. And from this point on, C2 slowly charges up to V following the time constant R1*C1.'

After having understood the phenomena, one can speculate a few things, i.e., (1) what if the source impedance is varied, (2) what if the cable length is changed, (3) what if the previous voltage is altered, and (4) what if the settling time is lengthened. The SPICE program was run for files with '.ALTER' statements for varying parameters. The results are shown in Fig. 5 and Fig. 6. Fig. 5a shows a readback voltage vs. source impedance plot with previous voltage at -10V, and Fig. 5b shows the same thing except with previous voltage at 0V. To verify the theory, a little experiment was conducted in the lab, and results are shown in Fig. 5b. Fig. 6 shows readback voltage vs. cable length plot. Experimental results are also shown in Fig. 6b.

2.4 MADC Input Impedance

Another frequently asked question is something like 'What is the input impedance of the MADC?' In answering to this, I say something like 'I don't know. What you see is the input of a AD509K voltage follower through two stages of HI507A multiplexers.' As discussed in the previous section, the resistive part of the input impedance is insignificant in high speed circuit analyses, and for this reason I have never taken a great effort to measure it. However, a simple minded experiment has revealed that multiplexers have very low leakage and that the input impedance near DC seems to be greater than 50M ohms.

2.5 MADC Specifications

Specifications are shown in Table 1, which is a duplicate of what had been given in a previous paper on the MADC (TM-931)[3]. The following points may answer some questions on specifications.

(1) The resolution is 12 bits with the MSB being the sign.

(2) The input voltage range is +10.235V to -10.240V with the LSB being 5 mV.

(3) The input impedance is greater than 50M ohms, which basically represents the input of a AD509K voltage follower. The leakage of multiplexers seems to be very low and not to affect the input impedance.

(4) The cycle time is 9.5 us with settling time and conversion time being 6 us and 3.5 us respectively.

3. Conclusion

After having studied some issues on the MADC, the author would like to make the following suggestions.

(1) Select a proper cable for your application, preferably a twinaxial cable, which maintains differential connections.

(2) Terminate cables observing the standard polarity convention using proper tools rather than fingers.

(3) Check the source voltage at the far end of the cable as well as at the near end.

(4) Lower the source impedance as much as possible knowing the fact that the source impedance really affects the accuracy of reading in high speed channel switching.

(5) Twelve microsecond (rather than 6 us) settling time will be used on the next generation MADC design.

(6) Don't measure the voltage of a floating battery. Don't ask a question like 'What is the input impedance of the MADC?' And etc., ...

References

1. P Bar Cable Installation, R. Ducar, Internal Memo, July 13, 1984.

2. User's Guide and Reference to SPICE, G. Tool, March, 1984.

3. A New Multiplexed ADC Unit, K. Seino, TM-931, December, 1979.

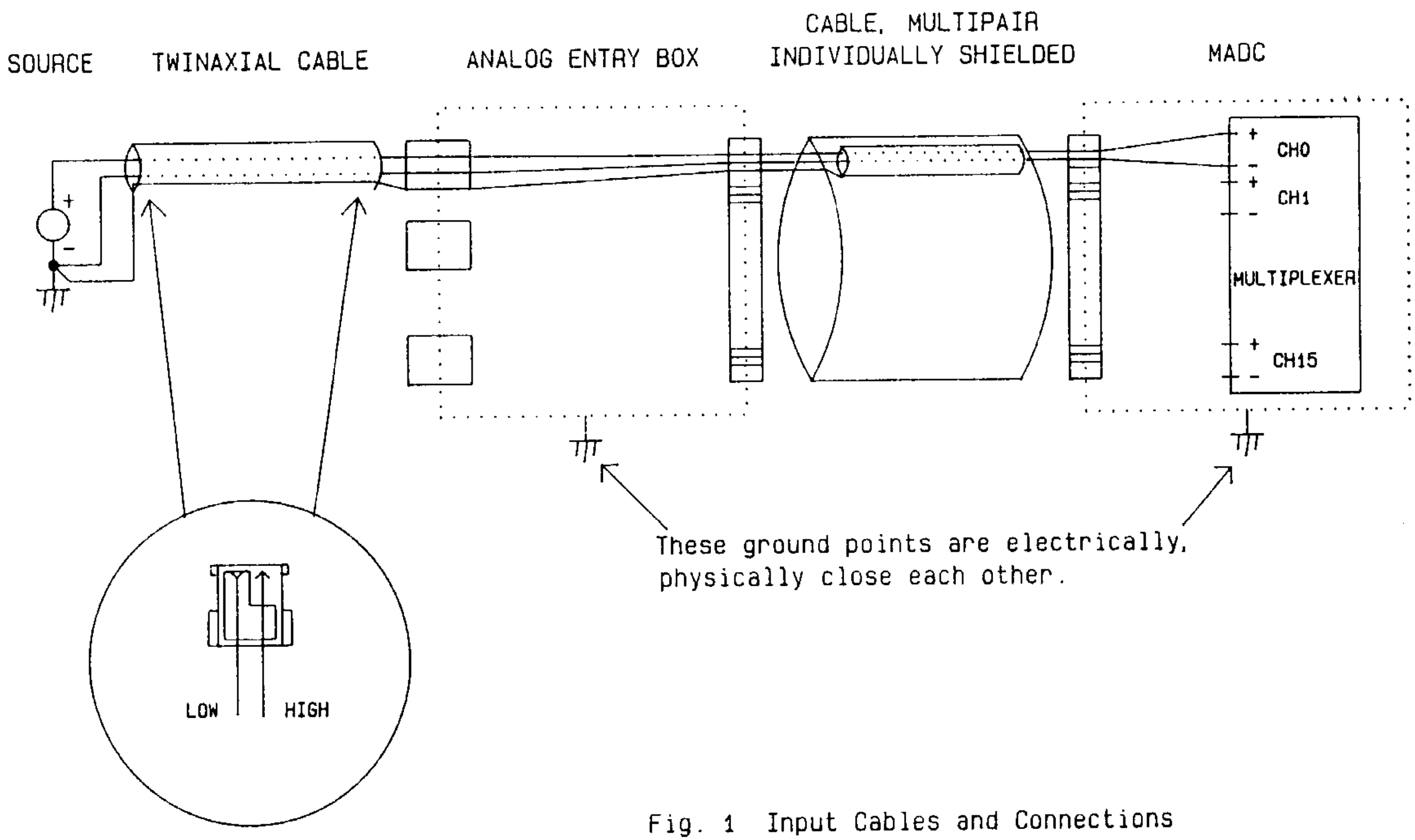


Fig. 1 Input Cables and Connections

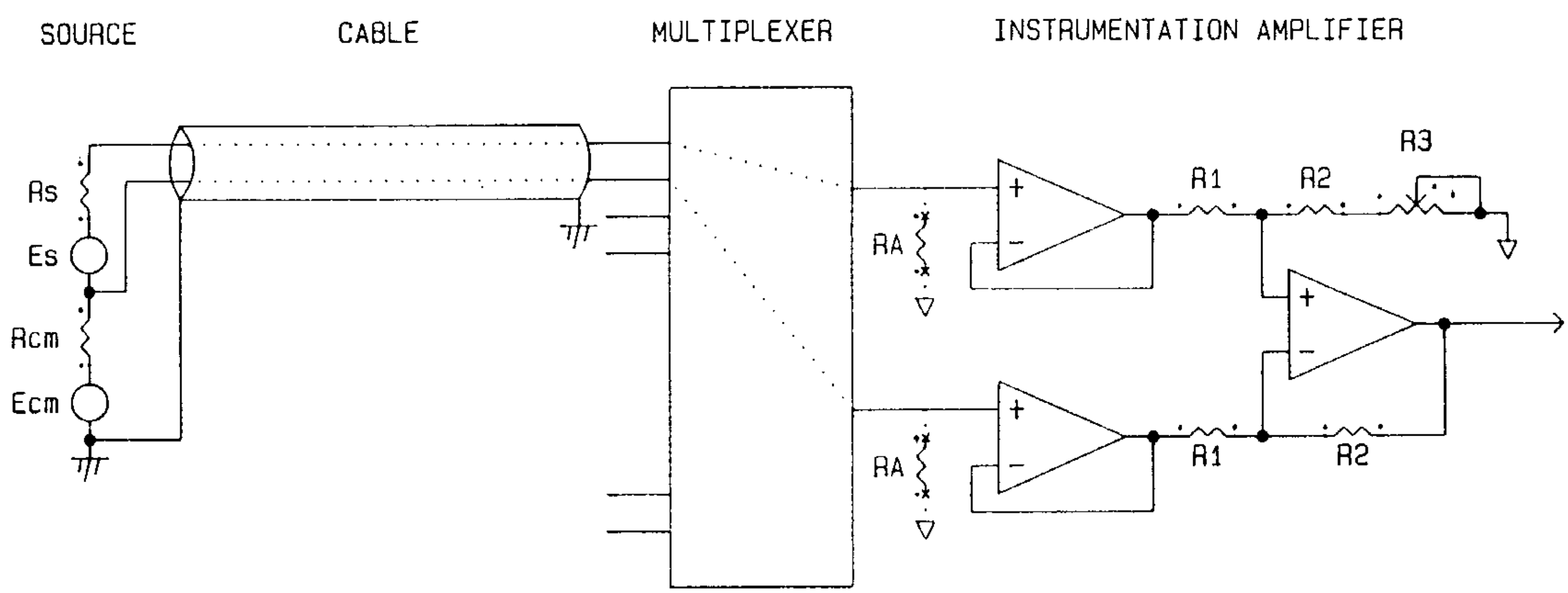


Fig. 2 Inputs of Amplifier Connected
to Source with Leakage Paths

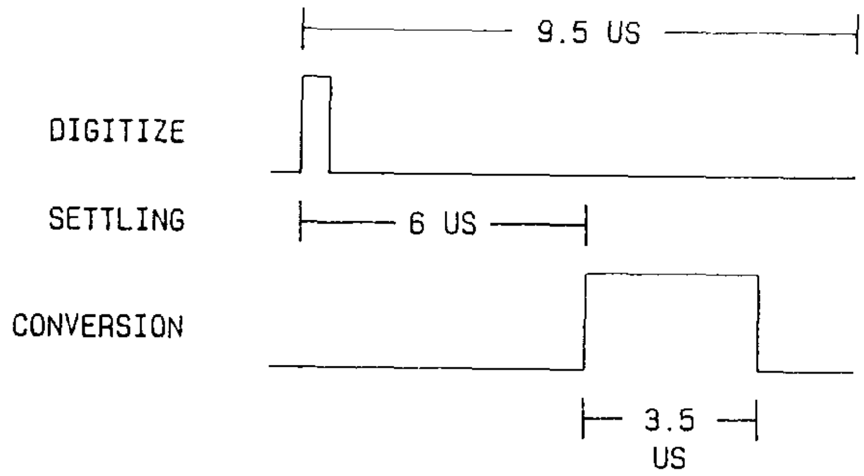


Fig. 3a MADC Timing

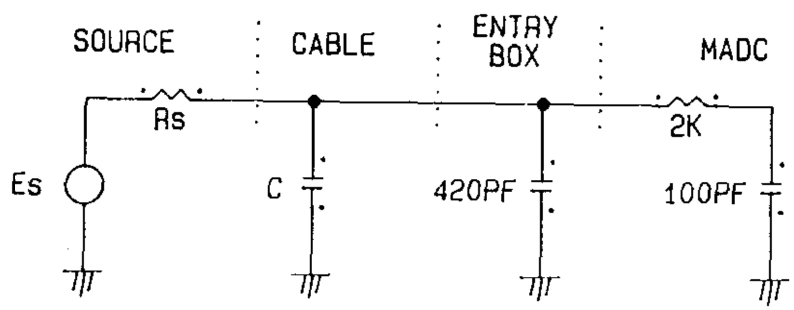
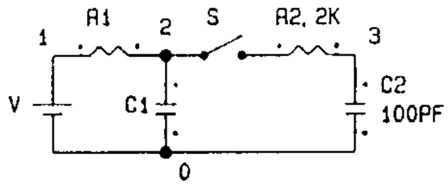


Fig. 3b MADC Input Circuit

Fig. 4a Simplified Circuit Used with SPICE




```
TEST CIRCUIT NO.3 - VRC/ RC
*
V 1 0 DC 8
R1 1 2 1K
C1 2 0 6800PF IC=8V
R2 2 3 2K
C2 3 0 100PF IC=0V
.TRAN 0.5US 20US UIC
.PLOT TRAN V(3), V(2)  (7.8, 8)
.PRINT TRAN V(3), V(2)
.WIDTH OUT=133
.END
```

Fig. 4b Listing of SPICE File

*: V(3)
+: V(2)

TIME	V(3)
0.000E+00	3.1191E-03
5.000E-07	7.300
1.000E-06	7.870
1.500E-06	7.901
2.000E-06	7.908
2.500E-06	7.914
3.000E-06	7.920
3.500E-06	7.926
4.000E-06	7.931
4.500E-06	7.936
5.000E-06	7.940
5.500E-06	7.945
6.000E-06	7.948
6.500E-06	7.952
7.000E-06	7.955
7.500E-06	7.959
8.000E-06	7.961
8.500E-06	7.964
9.000E-06	7.967
9.500E-06	7.969
1.000E-05	7.971
1.050E-05	7.973
1.100E-05	7.975
1.150E-05	7.977
1.200E-05	7.978
1.250E-05	7.980
1.300E-05	7.981
1.350E-05	7.983
1.400E-05	7.984
1.450E-05	7.985
1.500E-05	7.986
1.550E-05	7.987
1.600E-05	7.988
1.650E-05	7.989
1.700E-05	7.990
1.750E-05	7.990
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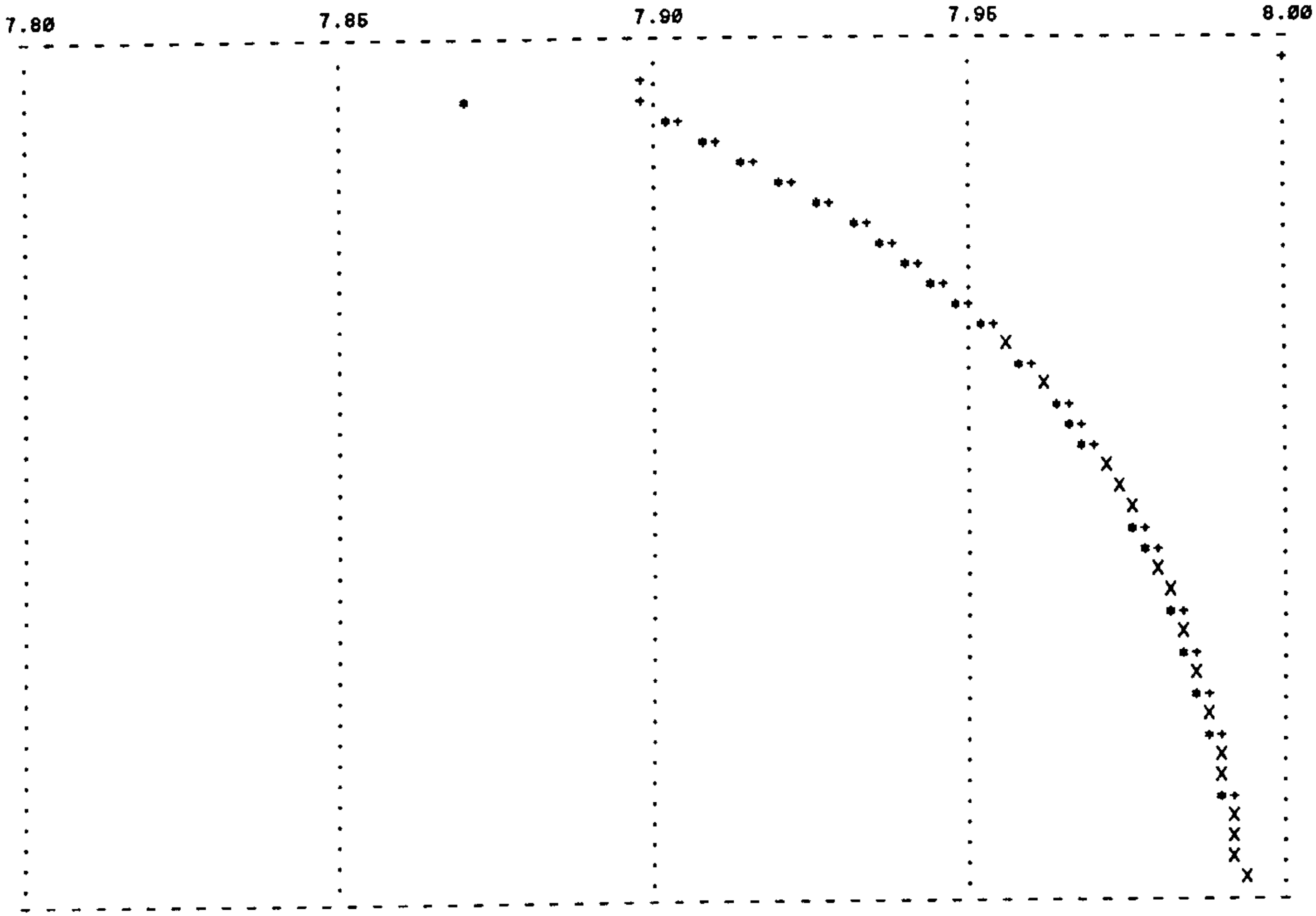

Fig. 4c Time vs. Voltage Plot

Fig. 5a *Readback Voltage vs. Source Impedance*

Source Voltage: 8V
Initial Voltage on Ci: −10V
Cable Length: 200ft, ~7200pf

Settling Time 12us: —o—o—o—
Settling Time 6us: —+—+—+—

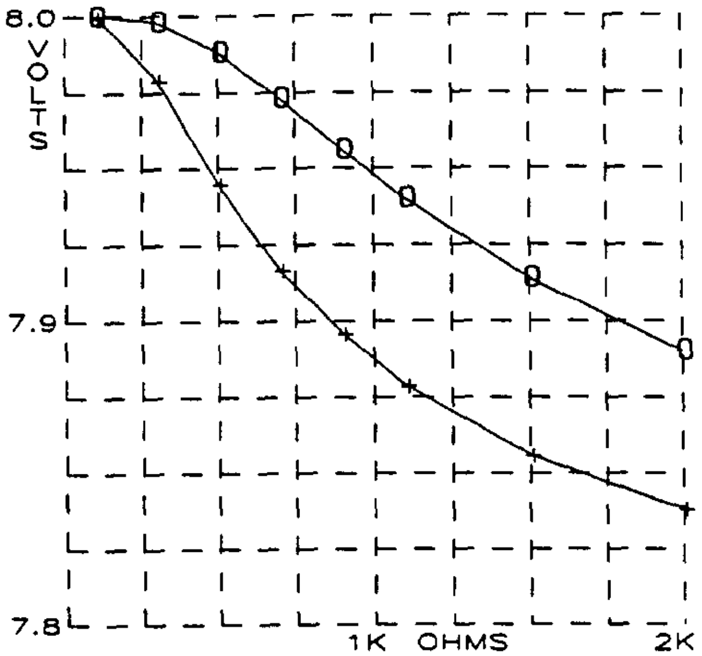

Fig. 5b *Readback Voltage vs. Source Impedance*

Source Voltage: 8V
Initial Voltage on Ci: 0V
Cable Length: 200ft, ~7200pf

Settling Time 12us: —o—o—o—
Settling Time 6us: —+—+—+—
Experimental Value: —x—x—x—

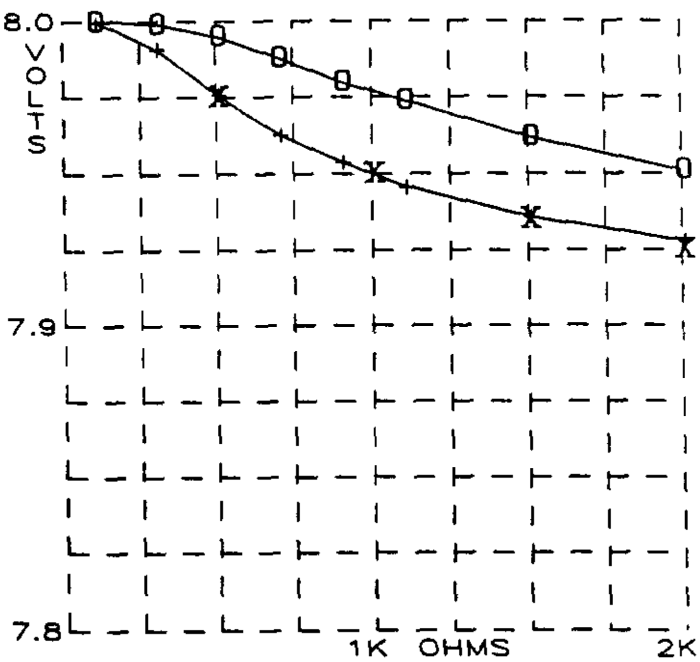

Fig. 6a *Readback Voltage vs. Cable Length*

Source Voltage: 8V
Initial Voltage on Ci: −10V
Source Impedance: 1K ohms

Settling Time 12us: —o—o—o—
Settling Time 6us: —+—+—+—

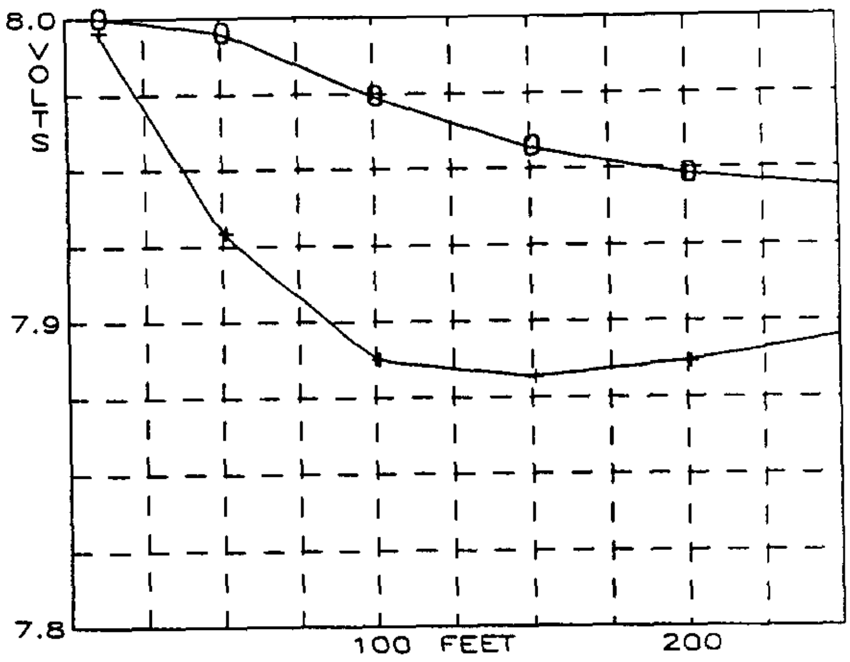

Fig. 6b *Readback Voltage vs. Cable Length*

Source Voltage: 8V
Initial Voltage on Ci: 0V
Source Impedance: 1K ohms

Settling Time 12us: —o—o—o—
Settling Time 6us: —+—+—+—
Experimental Value: —x—x—x—

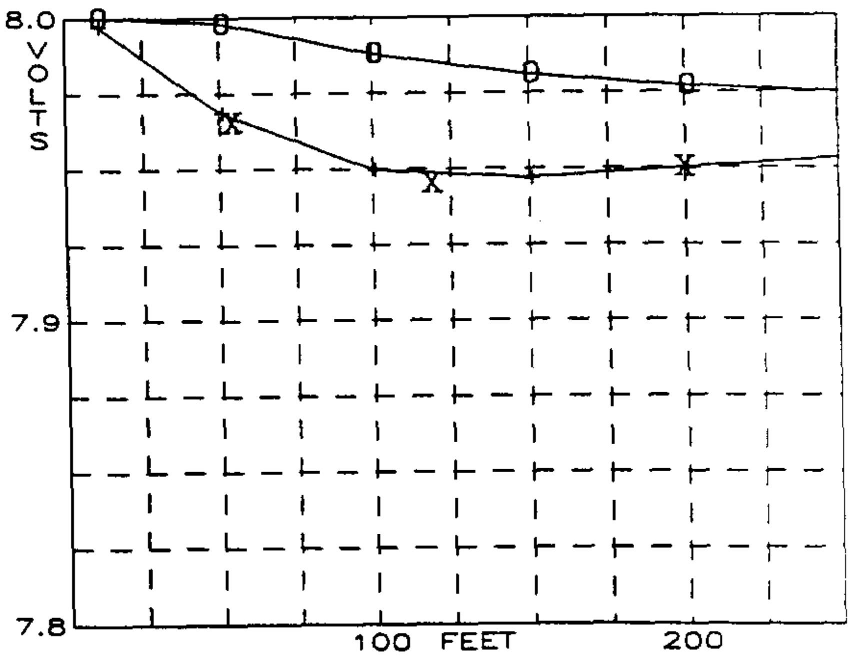

Table 1 MADC Specifications

Resolution	12 Bits (1 Sign, 11 Data)
Throughput Rate	100 KHz
Number of Channels	64 Differential
Input Voltage Range	+10.235V to -10.240V (LSB=5mV)
Input Common Mode Voltage Range	$\pm$12V
Input Voltage Protection	$\pm$35V
Input Impedance	50 M ohms min.
Accuracy at 25 degrees C	$\pm$0.049% of FS $\pm$1/2 LSB
Temperature Coefficient	$\pm$65 ppm/degree C max of reading
Channel Cross Talk	70 dB down min. at 6 KHz, from OFF channel to ON channel
Common Mode Rejection Ratio	74 dB at 60 Hz
Sample and Hold Accuracy	$\pm$0.01%
Sample and Hold Acquisition Time	1 us
Output Coding	Two's complement
Front Panel Dimension	19"W x 7"H
Main Chassis Dimension	16"W x 5 $^3/_8$"H x 13.5"D

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Illustrations